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Focal spot estimation of an Elekta dedicated stereotactic linear accelerator Monte Carlo model

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Abstract. The most challenging task in the Monte Carlo modelling of linear accelerators (linacs) is an accurate determination of the electron beam parameters striking the target which are characterised by the mean energy of incident electron beam and the electron beam shape, referred to as the focal spot. This work aims to determine the optimum focal spot size and shape of Elekta Axesse linac equipped with the Beam Modulator. A BEAMnrc Monte-Carlo linac model has been developed to produce a 6 MV photon beam. Different square field sizes of 2.4 cm, 4 cm and 10.4 cm were simulated in a simple water phantom with a source-to-surface distance of 100 cm. The simulation was performed with the incident electron beam energy of 6.2 MeV with the focal spot size varied between 0.1 and 0.3 cm with an increment of 0.05 cm. The field width (50% relative dose) and penumbra width (distance between 80% - 20 % relative dose) of the simulated profiles were compared with the measured profiles. This work found that an elliptical shape of the focal spot results in a better match with the measured data with the size of 0.2 cm in X-axis and 0.3 cm in Y-axis direction.

1. Introduction

There is an increasing trend of adopting stereotactic treatment for extracranial tumors such as early stage non-small cell lung cancer [1]. Its implementation has been supported by the introduction of high-resolution collimation systems which are able to generate high-resolution small fields of radiation [2]. Elekta has developed a Beam Modulator collimation system integrated into an Elekta Axesse linear accelerator which is specifically designed for stereotactic treatments [3].

Stereotactic radiotherapy requires accurate dose calculations for predicting and planning the radiotherapy treatment. The most powerful tool to accomplish this task is Monte Carlo simulation which has the capability to accurately model the particle transport through the linac head and phantom or patient geometry. This technique provides an independent verification, which is less labor intensive compared to a measurement based-technique.

However, the accuracy of the Monte Carlo modelling of the medical linac relies on the accurate determination of the electron source parameters, i.e. the energy of incident electron beam and the electron beam shape, referred to as the focal spot [4]. These parameters significantly influence the dose of the photon beam simulation [5]. It has been shown that the electron radial intensity distribution affects both the lateral dose profiles and the width of the penumbra [6, 7]. Determination of the radiation source



parameters for photon beam modelling have been reported by Sheikh-Bagheri *et al.* [4] and Pena *et al.* [8]. In their studies, the focal spot was assumed to have a circular shape, which has been also adopted by Heydarian *et al.* [2] in their Elekta Synergy S linac model. However, other groups reported that an elliptical focal spot in the model produced a better agreement with the measured dosimetry for a 6 MV photon beam produced by the Elekta Synergy linac [6, 7, 9]. It indicates that different linac machines will have different performance as well as a different optimum value of the radiation source parameters although they have the same nominal energy value. Therefore, it is important to use the published radiation source parameters only as an initial approximation.

This work aims to determine the optimum focal spot size and shape of a Monte Carlo model of an Elekta Axesse linac equipped with the Beam Modulator which is designed for stereotactic treatments.

2. Material and methods

The Elekta Axesse linac with a built-in Beam Modulator collimation system was modelled using the BEAMnrc Monte-Carlo code to produce a 6 MV photon beam [10]. The patient-independent components of the linac head model were the same as the previously commissioned Elekta Precise Monte-Carlo linac model [11], however, the collimation system was completely different. The Beam Modulator consists of 40 leaf pairs with a leaf width of 4 mm at the isocenter. The leaf has no tongue-and-groove design with a curved leaf end. As part of the Beam Modulator design, movable jaws have been replaced with a paired fixed inner jaw and a paired fixed outer jaw. Therefore, the treatment field size is only defined by the multi-leaf collimators (MLCs). The linac model has been previously commissioned to determine the optimum electron-beam energy, which has been found to be 6.2 MeV.

The focal spot size was optimized by varying the full width at half maximum (FWHM) of the Gaussian radial intensity distribution from 0.1 to 0.3 cm at a fixed value of the electron beam energy. The optimization process used an initial assumption that the focal shape was circular. Dose profiles and penumbra matching were used to determine whether the optimized focal spot is circular-shaped or elliptical-shaped [12]. Three different square field sizes (2.4 cm, 4 cm and 10.4 cm) were simulated in a water phantom with a dimension of $60 \times 60 \times 60 \text{ cm}^3$ with a source-to-surface distance of 100 cm. The lateral dose profiles were extracted at 10 cm depth and then compared with the measured dose profiles for the same depth. The dose profiles were normalized to the central axis dose for both simulation and measurement data. The field width was defined as the width between the 50% isodoses of the central dose profiles while the penumbra width was defined as the distance between 20% and 80% isodoses in the central dose profiles.

The Monte Carlo simulation consists of two stages. The first stage was the simulation of the photon beam through the treatment head components of the linac. The phase-space files were saved at a position just below the exit window of the linac, 55 cm from the target. These phase-space files were then used as the input for DOSXYZnrc simulations to produce the dosimetry data in the water phantom. The simulation used electron histories of 1×10^8 in the BEAMnrc simulation and $1\text{--}5 \times 10^8$ particles in DOSXYZnrc simulation. An electron cutoff of 0.7 MeV and a photon cut-off of 0.01 MeV were used in the simulation. To improve the simulation efficiency, the directional Bremsstrahlung splitting was used as well as range rejection with ESAVE of 2 MeV.

3. Results and discussion

The results show that lateral dose profiles of the photon beam are sensitive to the change of the focal spot size. This effect is more obvious for the small field size. As shown in figure 1, increasing the focal spot size results in a broader penumbra shape, and a decrease in the horns of the lateral profile shoulder of $2.4 \text{ cm} \times 2.4 \text{ cm}$ field. The FWHM of 0.2 cm gives a better match with the measured dosimetry data for the X-axis profile while the Y-axis profile shows the best match between measured and simulation for the FWHM of 0.3 cm.

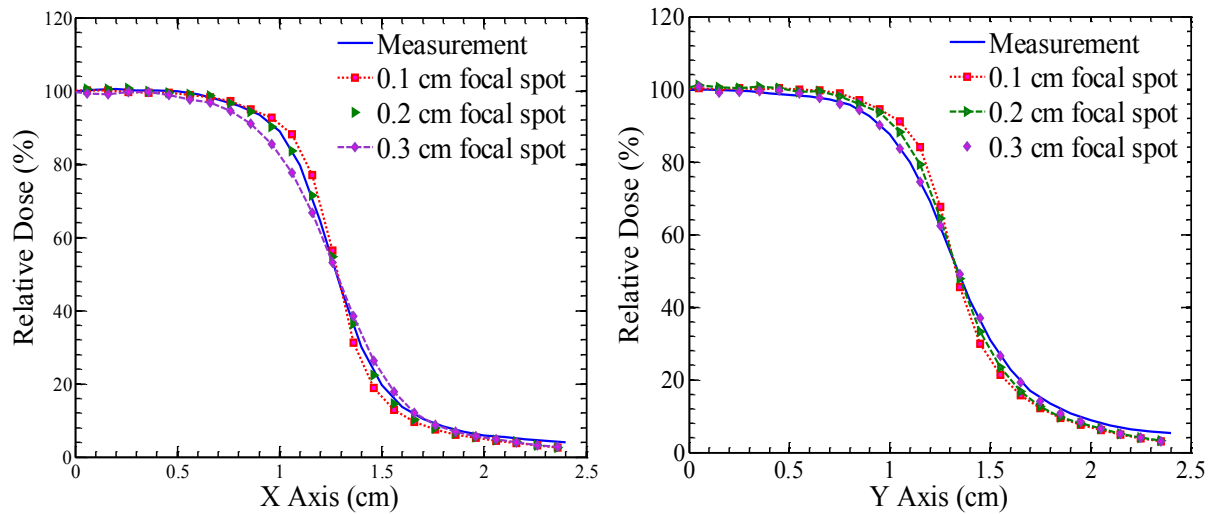


Figure 1. The inline lateral profiles (left) and the crossline lateral profiles (right) of $2.4 \times 2.4 \text{ cm}^2$ field showing the sensitivity of the lateral profiles to the change of the focal spot size. The best match was obtained at the focal spot size of 0.2 cm for the inline profile and 0.3 cm for the crossline profile.

The penumbra matching has confirmed that elliptical-shaped focal spot shows a better match with the measurement data rather than a circular-shaped focal spot. Figure 2 shows that the measured penumbra intersects with the simulated penumbra at 0.2 cm for the X-axis and 0.3 cm for the Y-axis.

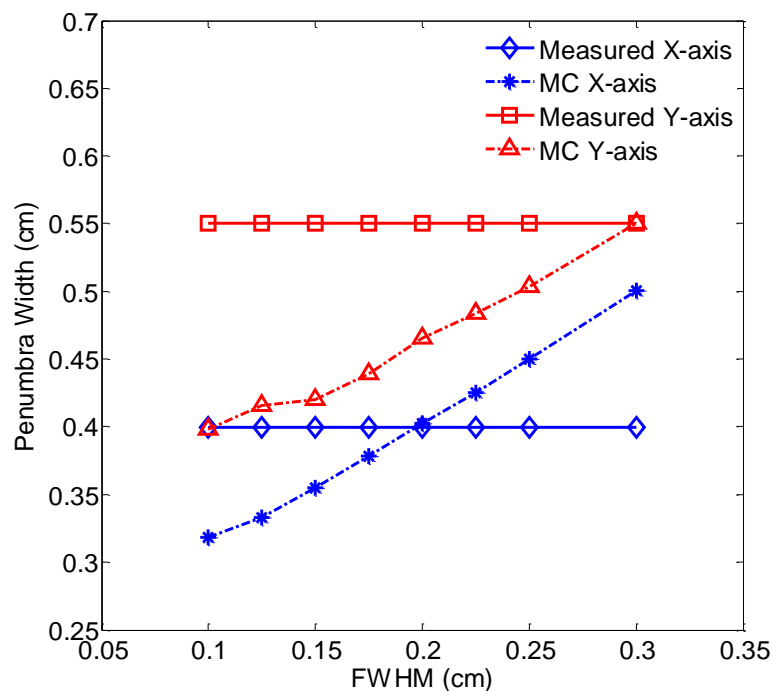


Figure 2. Penumbra matching of the measured (solid lines with markers) and simulated lateral profiles (dashed lines with markers) for a $2.4 \times 2.4 \text{ cm}^2$ field with variable electron beam FWHM.

Similar results have been found for $4 \times 4 \text{ cm}^2$ field and $10.4 \times 10.4 \text{ cm}^2$ field (figure 3), where the elliptic-shaped focal spot yields a better agreement with the measurement data. The optimum value is 0.2 cm in X-axis and 0.3 cm in Y-axis direction. The uncertainty of the Monte Carlo simulation is 0.4

% for the small fields and 0.6% for the large field (10.4 cm × 10.4 cm) over the flat region of the dose profiles.

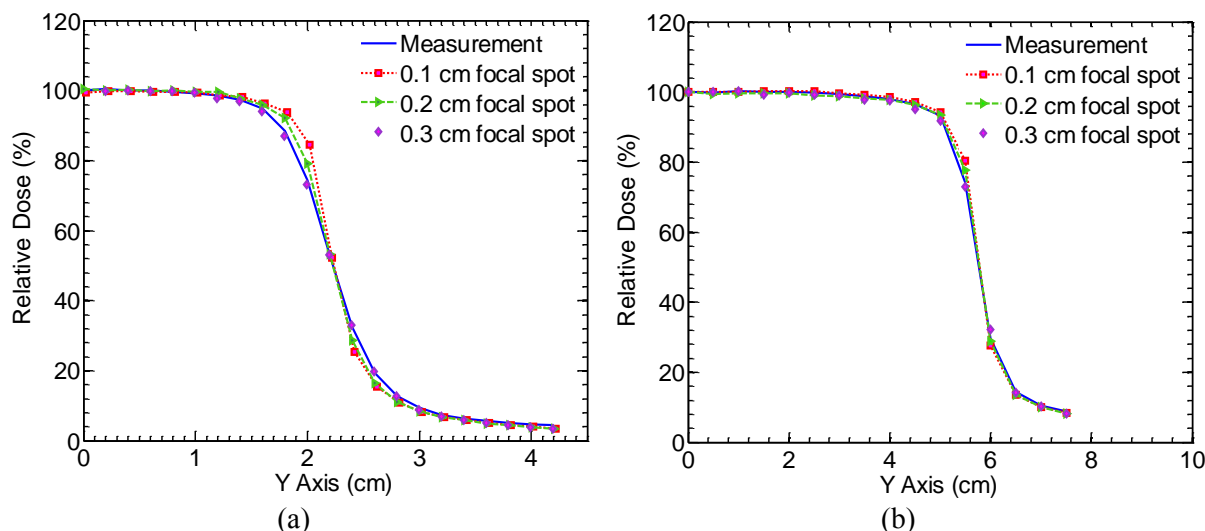


Figure 3. The crossline lateral profiles of 4 cm × 4 cm field (a) and 10.4 cm × 10.4 cm field (b). The focal spot size of 0.3 cm shows better match with the measured data.

The sensitivity of the small field size to the incident beam radial intensity distribution has been also reported by Pena *et al.* [8] and Keall *et al.* [5]. However, their models used an assumption that the electron beam radial intensity has an equal size in both X and Y axes. Similarly, Heydarian *et al.* [2] and Asnaashari *et al.* [13] used a circular-shaped focal spot size with an optimum value of 0.11 cm in their Elekta Synergy S Monte-Carlo model which also has a built-in Beam Modulator collimation system. However, Podder *et al.* [7] found in their study that the penumbra shape of the Elekta Synergy S is different between the leaf-end and the leaf-side penumbra, suggesting a focal spot asymmetry. The elliptical-shaped focal spot approach has been also used by Francescon *et al.* [9] and Almberg *et al.* [6] in their Elekta Synergy S model.

As the Elekta Axesse linac has a similar design as the Elekta Synergy, it is assumed that its radiation source parameters would be the same. We found that an elliptical-shaped focal spot gave the better match with the measurement data for the Elekta Axesse linac, however, the optimum spot size found in this study is slightly larger than that was reported by Francescon *et al.* [9], which is FWHM_x = 0.2 cm and FWHM_y = 0.09 cm.

4. Conclusion

The Monte Carlo simulation has been employed to estimate the focal spot size of the Elekta Axesse linac dedicated for the stereotactic treatment. The study showed that an elliptical-shaped focal spot results in a good agreement with the measurement in both inline and crossline direction. The optimum focal spot size has a size of 0.2 cm in the in-line direction and 0.3 cm in the cross-line direction. The model will be further employed for studying clinical stereotactic treatments involving small field sizes.

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